3D Modeling for Endoscopic Surgery

Dr.-Ing. Uwe G. Kühnapfel
H.K. Çakmak
Dr.-Ing. H. Maaß

IEEE-SB Symposium on Simulation
Delft, NL
October 13, 1999
Overview

Introduction to M.I.S. Simulation

Structure of the M.I.S. Training System

Modelling of Soft Tissue

Simulation of Surgical Interactions

Visual Effects for Simulation Realism

Other VR applications in medicine

Conclusions
The “Karlsruhe Endoscopic Surgery Trainer”

„Phantom Box“ with user interface:
   2 MIS-instruments, 1 Endoscope,
   6 footswitches

PC based position measuring system

Rendering and Simulation with KISMET software on:
   • SGI-workstations (Onyx, Octane) and
   • NT-workstation (Intergraph, SGI-Visual PC)

Force-Feedback with commercial haptic devices:
   • Impulse Engine (Immersion Corp.)
   • PHANToM (SensAble Technologies)

➢ PhD-thesis Dr.-Ing. Kuhn Ch., FZK - IAI, ’97
Schematical Diagram of the Laparoscopy-Trainer

- **measurement device**
- **data transformation**
- **digital data**
- **forces**
- **high-performance graphic workstation**
- **graphical user interface**
- **model database**
- **model knowledge-base**
- **visual data**
- **virtual endoscopic view: operation area**

**User interface:** laparoscopic trainer

**Imitations:** endoscopic camera, instruments

**Binary control signals**

**Foot switches**

**KISMET**
Trainer-Box (Current)

- 2 “Instruments” (up to 4)
- 1 “Endoscopic Camera”
- 6 Foot-Switches
- Potentiometers as Sensors
- No Force-Reflection
Integration of two commercially available Force-Feedback Input Devices with KISMET
• „Laparoscopic Impulse-Engine“ (Immersion)
• „Phantom“ (Sensable Technologies)

Research on „Feeling of Tissue Elasticities“ in MRI-Volume Datasets
Elastodynamical (physical) Models Nonlinear Spring-/Mass Systems with Damping

Freeform-Surfaces as basic Primitives for Modelling

- various rendering types and Smoothing-/Quality-Levels, Texturing

Computational Tissue-Modelling
Elastodynamical tissue model

- Nonlinear viscous mass-spring model
- System of coupled differential equations

**Lagrange Equation (ODE 2nd Order):**

\[
m_i \cdot \frac{d^2 x_i}{dt^2} + \gamma_i \cdot \frac{d x_i}{dt} + g_i(t, x_i) = f_i(t)
\]

- \(m_i\): Mass of knot
- \(\gamma_i\): Damping
- \(g_i\): Inner forces
- \(f_i\): External forces

**Numerical solution of ODEs**

\[
v_i^{t+\Delta t} = k_i \cdot \left[ v_i^t + \frac{\Delta t}{m_i} \cdot (f_i^t - g_i^t) \right]
\]

\[
k_i = \frac{B_i}{1 + \frac{\Delta t \cdot \gamma_i}{m_i}}
\]

**Newton-Euler Integration**
Mechanical Properties of soft tissue

Experiments
- in-vivo and post-mortem
- uniaxial tensile tests
- compression tests

Tissue model
- Polynomial 4th order

Results
- Different properties in-vivo and p.m.
- Stress/Strain curves organ specific
- Linear slope for compression: 0% - 15%

\[ \sigma = E_z \cdot \varepsilon_z \cdot (1 + a_2 \varepsilon_z + a_3 \varepsilon_z^2 + a_4 \varepsilon_z^3) \]

PhD-thesis Dr.-Ing. Maaß H., FZK - IAI, ´99
### Speed-of-Sound and E-Modulus Range Tables

**E-Modulus in MPa**

<table>
<thead>
<tr>
<th></th>
<th>0</th>
<th>0.1</th>
<th>0.2</th>
<th>0.3</th>
<th>0.4</th>
<th>0.5</th>
<th>0.6</th>
<th>0.7</th>
<th>0.8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fat (soft)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fat (not soft)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Liver</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spleen</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heart-Muscle</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kidney</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Speed of Sound in m/s**

- Fat (soft)
- Fat (not soft)
- Liver
- Spleen
- Heart-Muscle
- Kidney

- post mortem
- intra vitam
Implementation of the Software-Tool *KisMo* for elastodynamical Objects

Modelling-Tool *KisMo* (KISMET-Modeller)
Modelling-Tool: KisMo (KISMET-Modeller)

- Interactive design of model geometry and spatial nodal net
- SceneEditor for model connectivity
- Spline modelling
- Multilayer functionality for volumetric cell definition
- Volume rendering of CT/MR-data

Modelling of soft tissue
Surgical Simulation Scene

Application 1
Cholecystectomy

Clinical partner
Universitätsklinik Tübingen
Prof. Buess (since 1995)

Technical Details
Objects: 2
Knots: 325
Springs: 1317
Performance: 24 fps (SGI OnyxIR2, 2 CPU)
17 fps (SGI OctaneMXE, 2 CPU)
15 fps (SGI VPC-320, 2 CPU)
9 fps (Intergraph PC, 2 CPU)

PhD-thesis Dr.-Ing. Kuhn Ch., FZK - IAI, ´99
MIS-Training System for Cholecystectomy

- Implemented on a Silicon Graphics Onyx-RE Workstation (2 CPU’s MIPS R4400)
- Input-Devices: 2 MIS-Instruments, Endoscopic Camera, No Force-Feedback
- Clinical Partner: MIC-Tübingen (Prof. Buess)
Surgical Simulation Scene

Application 2
Gynaecology

Clinical partner
Universitäts-Frauenklinik Kiel
Mrs. Prof. L. Mettler (since 1997)

Technical Details
Objects: 21
Knots: 2.847
Springs: 11.326
Performance: 12 fps (SGI Octane, 2 CPU)
9 fps (SGI VPC-320, 2 CPU)
6 fps (Intergraph PC, 2 CPU)
Basic Surgical Interactions

- Grasping
- Application of clips
- Coagulation
- Cutting

Surgical Interactions with deformable objects
Modelling of Slings

Instrument design
Deformable Effector modelled as Spring-Mass System

Linkage
Inflation
Stabilization
Sling Mechanism and Interaction

Sling mechanism

Surgical Interactions with deformable objects
Simulation of Suturing

- Suture material modelled as Spring-Mass-System
- Collision management

Surgical Interactions with deformable objects
Suture Interaction

Surgical Interactions with deformable objects
Irrigation and Suction

- Implementation of Particle Systems
- Motion blurred particle rendering
- Tissue deformation: Particle impact
- Fluid accumulation
- Effects: Splashing
  - Reflection
  - Ripples
Morphodynamics

Pulse Simulation

- Propagation of force waves
- Hierarchical vessel tree
- Parameters: Pulse frequency, Force per vessel, Wave speed p.v.
Morphodynamics

Intestine / Stomach Motion, Respiration, Pulse

- Axial forces onto each ring ($F_1$) and in-/deflating forces from central knots to geometry knots ($F_0$)

- Forces time/knot dependent

- Parameters: Force („Blood pressure“)
  Wave speed and frequency
  Random

$$F_k(t,i) = (A_k + \text{rand}) \cdot \sin(vel_k \cdot 2\pi \cdot t - freq_k \cdot 2\pi \cdot i + \text{rand})$$
Active Deformable Objects

Pulse Simulation

- Propagation of force waves in hierarchical vessel tree
- Inflating Forces
- Parameters:
  - Pulse frequency
  - Force
  - Wave speed

Organ motility: Stomach/Intestines

- Axial and inflating Forces $F_k(t,i)$
- Parameters:
  - Force amount
  - Wave speed, frequency
Arterial Bleeding

- Particle System Simulation
- Coupled with Pulse Simulation
- Application of clips to stop bleeding
- Accumulation of blood
- Parameters: Blood loss per vessel
  Rendering settings
Steam / Smoke for Coagulation

- 3D-Procedural Textures
- Billboard-technique
- Animation: Texture shifting
  - Spline Key-Frame
  - Color / Transparency
- Steaming up of endoscopic lens
The Karlsruhe Endoscopy Training System for the Minimally Invasive Surgery in Gynaecology

Video

Virtual M.I. Surgery Simulation
(c) FZK-IAI 1999 by Çakmak H. K.
VR Applications: OR-Design, Medical Telerobotics

Applications:

- telerobotics, telesurgery
- surgical manipulator development
  (kinematics, workspace studies ... )
- instrument development
  (design studies)

Purpose:

- discussion with surgeons
- prototyping
- operation theatre ergonomy
- project presentations
- training of medical personnel
VR-Applications: Volume-Rendering, Navigational Support

- Realtime visualisation of volume data (CT, MR),
- Virtual endoscopy
- Diagnostics support

- Surgical Planning
- Interventional radiology
Conclusions:

- Training System for minimally invasive surgery with realistic user-interface
- Methods for realistic Modelling of deformable objects
- Realtime Simulation of Surgical Interactions: Grasp, Clip, Cut, Coagulation, Irrigation, Slings, Suturing
- Active deformable objects: Organ motility
- Particle Systems for fluid simulation

VR-based Surgical Simulation Systems will become more realistic in the future
- They will be integrated into multimedia teaching and training environments
- All surgical disciplines will be covered

more and actual info’s: http://www-kismet.iai.fzk.de